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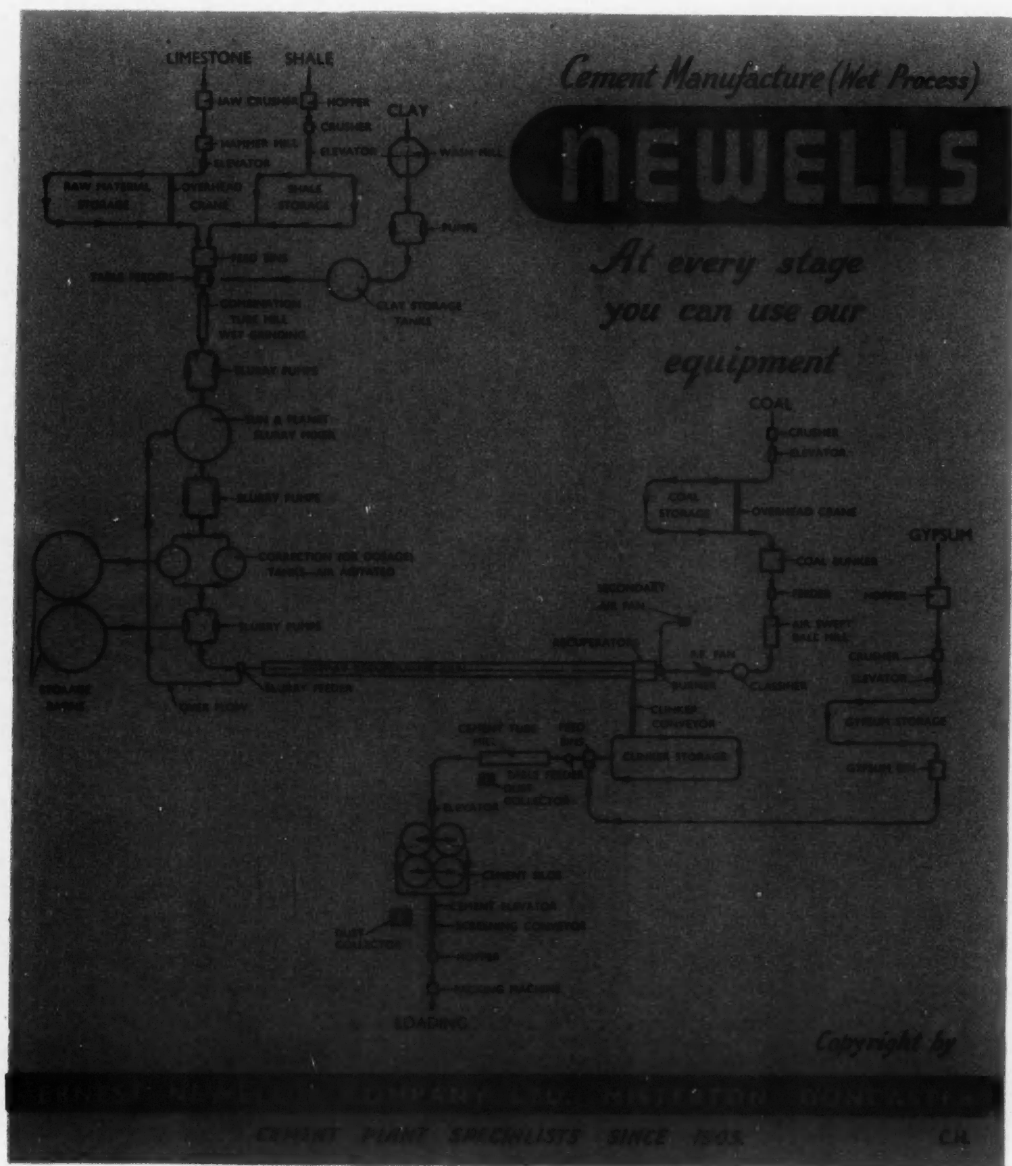
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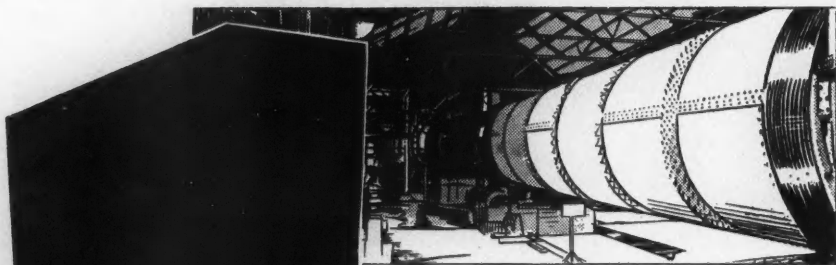
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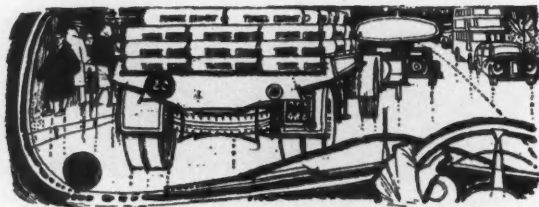
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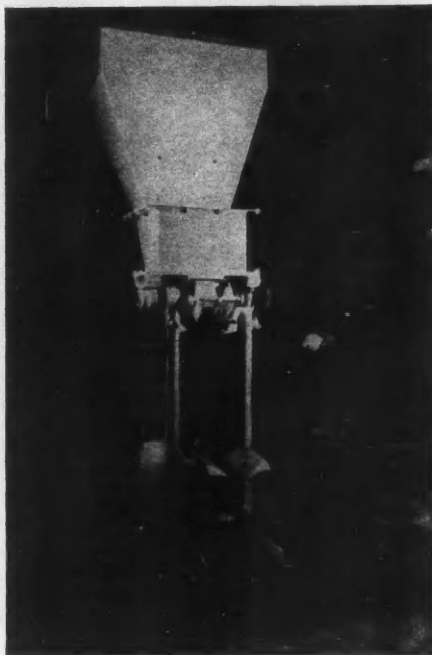


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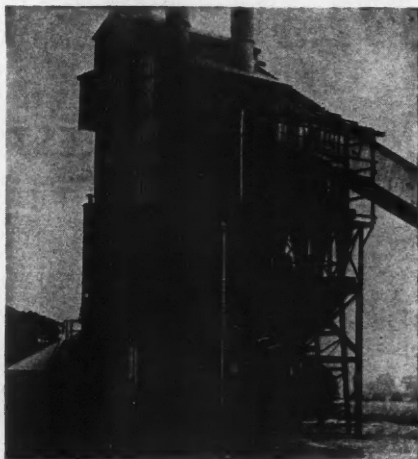
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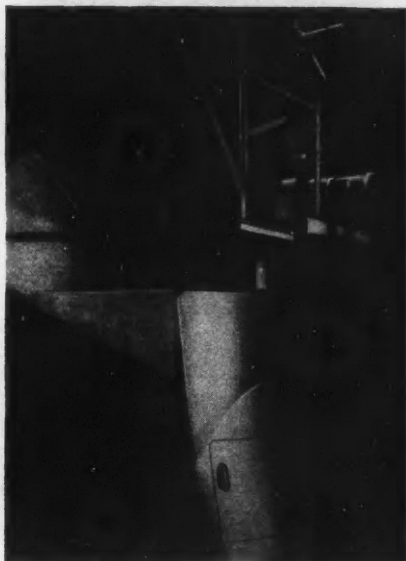
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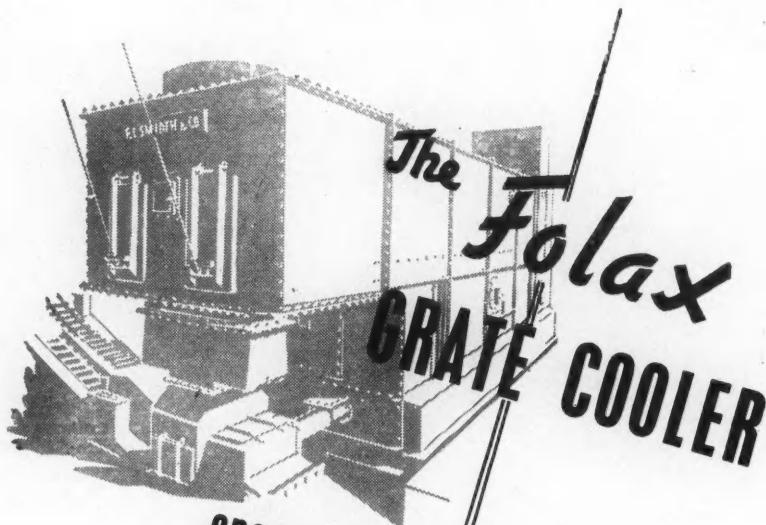
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VOLUME XXIX. NUMBER 2.

MARCH 1956

The Physical Structure of Cement and Concrete.

By T. C. POWERS

MANAGER OF THE BASIC RESEARCH SECTION OF THE
AMERICAN PORTLAND CEMENT ASSOCIATION.

The following is a report of a lecture arranged by the Cement and Concrete Association, and given by Mr. Powers in London in March.

The Nature of Concrete.

In *Fig. 1* is shown a specimen of concrete made by the speaker about twenty years ago in which the coarse aggregate was replaced with steel balls, and this gives a very graphic illustration of one of the most significant features in the structure of concrete. The concrete was of very stiff consistency and compacted by a laboratory vibrator. It is seen that some of the balls have been torn away from the

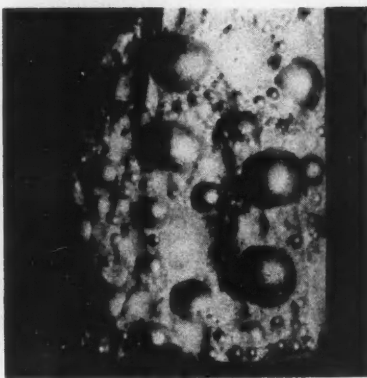


Fig. 1.

(13)

matrix. Between the balls is mortar in which the sand particles are separated by hardened cement paste on which the properties of concrete depend to an important extent. A mixture of cement and water comprises the volume of cement (that is its weight multiplied by its specific volume) plus the volume of the water. Hardened cement paste is a porous solid composed of hydrated cement, unhydrated cement, and pores that can be occupied by water; when the specimen is dry it can absorb water up to possibly 50 per cent. of its own volume and when exposed to dry air it can lose water, so porosity is defined as space for evaporable water in the specimen. Two specimens of equal weight, containing equal amounts of Portland cement having reacted to the same degree and which are air dry, can occupy a very different volume, and the differences in physical properties must be related to the difference in specific volume. One specimen might contain 0.25 gr. of water per gramme of cement in the original paste, and the other 0.70 gr. of water per gramme of cement; this illustrates the meaning of water-cement ratio in physical terms with respect to specific volume, or the amount of solids per unit volume of paste.

The Setting of Cement.

When the paste changes from its original plastic condition, or almost fluid condition, to the solid state there is a network of cement particles in water-filled space. Chemical reactions take place between the minerals of the cement and the water, and a new solid is produced. In *Fig. 2* the original cement is represented by the single-hatched area with the space occupied by water above it for different water-cement ratios. The situation when 33 per cent. of the cement has been hydrated is shown at (b). The double-hatched area below the top of the original single-hatched area is one-third of the total amount of cement present, and the volume of the new product is indicated by all the double-hatched area. As the cement reacts with the water the new solid it produces occupies more space than the amount of cement consumed. At (c), 6 per cent. of the cement is hydrated and one-third remains unhydrated. At (d) all the cement is hydrated; the examples on the right show that, for different water-cement ratios, when all the cement has been hydrated there is still a water-filled space in the specimen.

In order to ascertain the nature of the substance that fills the originally water-filled space in the paste, the fixation of water, that is the volume of water that is chemically combined and the volume of water that is combined in less definite ways—physically or, more specifically, by physical adsorption—has been studied. Work was done on capillary theories evolved from early work in Germany, and also with theories that applied quite well to soils. But it was hoped to discover the nature of the porous structure, or the distribution of pore sizes, by discovering how the water would be held by the paste at different vapour pressures or relative humidities. Before that work was completed the Brunauer, Emmett, and Teller theory of adsorption appeared. The actual surface on which the water molecules were captured from the air by a dried sample of any surface could be computed. In these cases a sample of dry hardened cement paste, when exposed to moist air, would take up the water in very definite amounts, the amount being a function

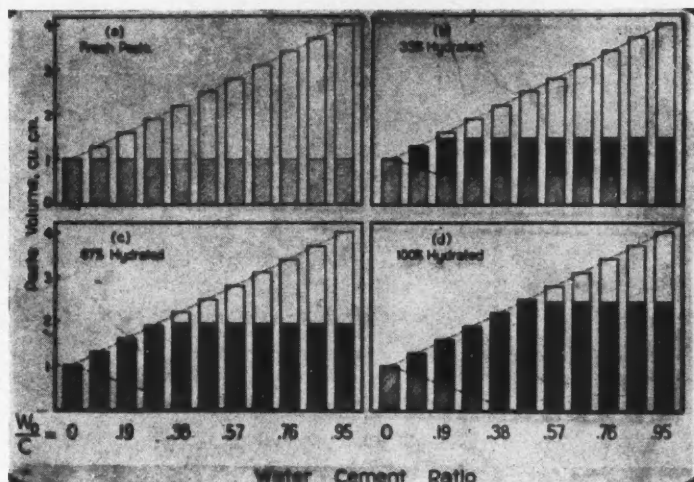


Fig. 2.

of the relative humidity of the air. This theory, reduced to a simple mathematical form, gave a factor that was proportional to the surface area of the particles that make up the solid material. These particles were very small (in the colloidal range of dimensions) and, since they were obviously forming a solid, such a colloid was called a gel. There are other products in the spaces previously filled with water, particularly crystalline calcium hydroxide, but the predominant material is the gel.

The Properties of Cement Gel.

By studying water vapour adsorption and water fixation, together with measurements of the porosity, that is the space occupied by evaporable water, the gel can be described in the following common physical terms: (a) Specific surface of colloidal hydrates; (b) Gel-particle size—not shape (from volume and surface area; the volume is obtained from the measurements of porosity, and the surface area from the measurements of adsorption; (c) Fraction of cement hydrated (from the measurement of the fixation of water, that is from what may be called the non-evaporable water content; this term is used because it was not certain what part of it was chemically fixed and what was not chemically fixed.

The physical properties of gel that have been measured are, first, the physical properties of the nominal cement gel. No correction is made for the amount of calcium hydroxide present. The density of the gel is 2.15 gr. per cubic centimetre, its porosity is about 26 per cent., and it has a coefficient of permeability to water under pressure of 2×10^{-15} cm. per second; that is less than that of natural rocks, except those that are single crystals. The gel substance proper has an average density of 2.60 gr. per cc., which is not very different from that of silicates. The specific surface area is 650 sq. m. per cubic centimetre, or 250 sq. m. per gramme,

which is a different magnitude from that of the original cement. The diameter of the gel particle, expressed on the equivalent-sphere basis is about 87 ångström (Å) in diameter. There is no clear evidence that the particles are spherical, but this is assumed for convenience in calculations.

The density of cement paste varies with the amount of gel or of its complement the amount of capillary pores. The water-filled space in the paste becomes partly replaced by cement gel, but the gel is a granular material, probably fibrous with a characteristic porosity; the pores are called gel pores. The space that was originally water-filled is partly filled by this porous material; the part that is not filled is called capillary pores.

A given cement produces the same reaction product at all stages of its hydra-

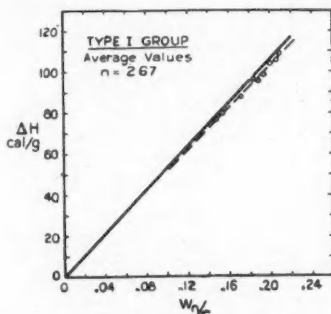


Fig. 3.

tion, except for gypsum reactions, as is shown by (a) The constant specific surface of the gel (from one day to fourteen years), (b) Constant heat of hydration per unit of combined water (from one day to twelve years), and (c) Constant ratios in X-ray patterns (up to twenty-eight days). A few years ago most research workers did not, for good reasons, believe that this was true. Portland cement comprises four major compounds, namely tricalcium aluminate, dicalcium silicate, tricalcium silicate, and tetracalcium aluminoferrite. The aluminium-bearing compounds hydrate first, the tricalcium silicate follows, and finally the dicalcium silicate, with some overlapping. This seemed to explain the fact that cements having different compositions hydrated at different rates. But if that is so, the early reactions should produce a different product from the later reactions. But it is found, by these methods of examination, that this is not true for cements of the usual range of composition.

Fig. 3 shows the heat of hydration of cement plotted against the amount of combined water—or the non-evaporable water. If only one compound were present, for example tricalcium silicate, it is clear that, since the amount of water combined is in proportion to the amount of tricalcium silicate which would have hydrated, each increment is related to a very definite amount of heat, so that tricalcium silicate should produce a straight line on such a graph, and it does so. Dicalcium silicate should also give a straight line when treated by itself, and it

TABLE I. X-RAY DATA ON THE HYDRATION OF CEMENT.

Age	Relative intensity	
	For $\frac{C_2S}{C_3S}$	For $\frac{C_3A}{aC_2S + bC_3S}$
0	1.11 \pm 0.09	0.57 \pm 0.08
2 hours	1.18 \pm 0.12	0.60 \pm 0.05
6	1.26 \pm 0.17	0.94 \pm 0.30
1 day	1.08 \pm 0.29	0.53 \pm 0.02
2 days	1.06 \pm 0.26	0.58 \pm 0.02
3	1.02 \pm 0.10	0.60 \pm 0.07
4	1.14 \pm 0.16	0.83 \pm 0.13
7	1.07 \pm 0.02	0.70 \pm 0.06
14	1.10 \pm 0.19	0.82 \pm 0.16
28	1.45 \pm 0.29	0.82 \pm 0.08

does so but with a different slope. Therefore a cement (the points in *Fig. 3* represent a group of A.S.T.M. Type I cements) should produce a curve or a break in the line, but, although the points represent ages from one day to one year, there is no indication of a break in the line. The specific surface of the gel should also be a function of composition; if there were sequential reaction the specific surface would have the same kind of relationship with the non-evaporable water.

The data in *Table I* is obtained when X-ray diagrams are used to determine the amount of unhydrated compounds in cement paste. At zero age none of the cement is hydrated. The ratio of the intensity of the tricalcium silicate and dicalcium silicate lines is 1.11 with a standard deviation of 0.09. The tricalcium aluminate, as a ratio of a function of the two silicates, is 0.57 ± 0.08 . At two hours the figures appear to be about the same, considering the standard deviation; at six hours they have changed, but not significantly, and so on until at twenty-eight days there is no evidence that one component is disappearing faster than the other. It is particularly surprising that the tricalcium aluminate, which is supposed to disappear in two or three days, is still present at twenty-eight days. Even the X-ray diagrams show one of the lines of the tricalcium aluminate very plainly at twenty-eight days. The practical significance of this is that in the process of filling up the structure in the paste the same kind of material is produced all the time. More and more of the same kind of gel is produced, tending to fill whatever amount of space is present, and obviously the physical properties will depend on how much space was present in the first place and how much of it becomes filled. It is not so much a matter of how much of the cement becomes hydrated, but of how much of the water-filled space is filled.

Fig. 4 is a photograph of a model that helps to form a picture of what the substance that is being produced and is filling up the water-filled space might look like. The spheres represent the gel particles, and the spaces between them are the gel pores; the spaces marked C represent residues of the original water-filled space and are the capillary pores. If the model corresponded to a porosity of 26 per cent. the picture would be an opaque mass, because stacked cannon balls in hexagonally close-packed spacing have a porosity of 26 per cent. If it is assumed

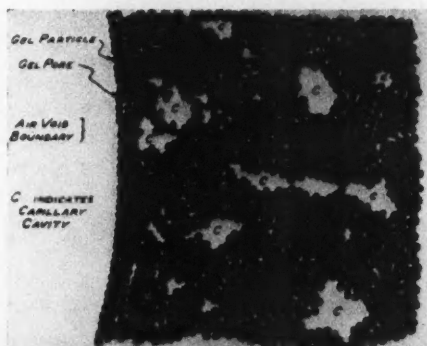


Fig. 4.—Simplified Diagram of Structure of Paste.

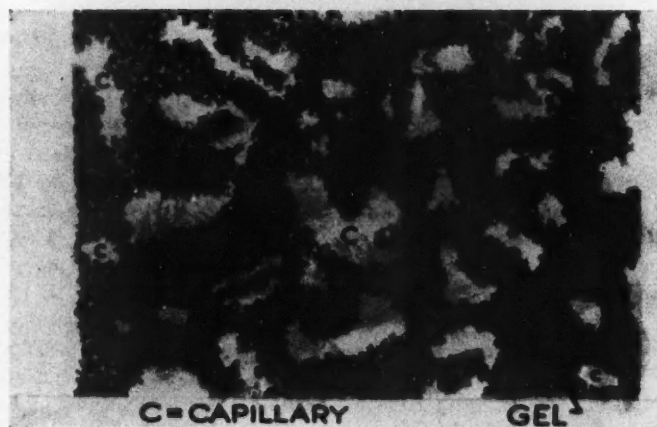


Fig. 5.—Capillary porosity 20 per cent. Water-cement ratio 0.5.

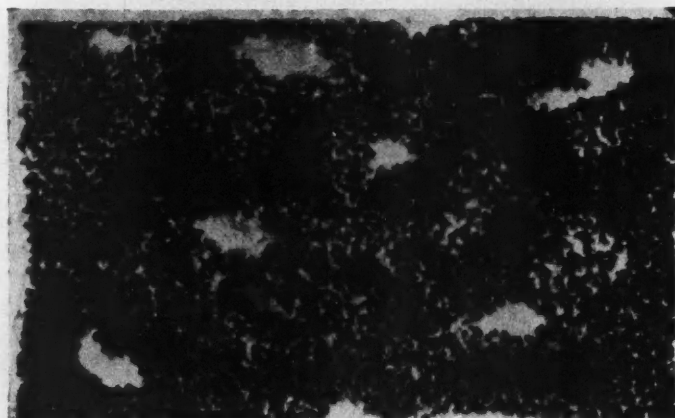


Fig. 6.—Capillary porosity 7 per cent. Water-cement ratio 0.3.

that the particles are fibrous, the picture might be something like that shown in *Fig. 5*; this is drawn in such a way that, if it were a cross-section, the spaces would correspond to a capillary porosity of 20 per cent. of the volume, and that is what is found with a water-cement ratio of 0.50.

Capillary porosity can be reduced either by producing more of the same material from the unhydrated cement by further curing or, at a given stage of hydration, by using a lower water-cement ratio. *Fig. 6* indicates the result of decreasing the water-cement ratio; the picture corresponds to a water-cement ratio of 0.30 and a capillary porosity of 7 per cent. of the volume. This is diagrammatic, but it accords with the data; it is the kind of system that should behave very much as cement pastes have been observed to do. It is clear that this is related to strength. The gel is made up of very fine materials, with a high specific surface, fastened together so as to form a semi-solid material. Cement gels, if they have been previously dried, swell if they are put in water; but instead of becoming soft and losing their strength, they swell only a microscopic amount and then stop swelling. There is no adequate theory for strength, but perhaps the following is a reasonable idea. Cement gel has a finer texture than clay, which has a certain amount of strength associated with the fact that it has a very fine texture; the physical forces between the grains tend to bind it together. Those forces must also be present in cement paste. The fact that the strength varies as the water content is varied might be evidence of such a phenomenon. But the fact that the swelling is limited is direct evidence that there are bonds other than physical ones. The penetration of water can break the bonds in clay, but where penetrating water does not break the bonds it is assumed that there are chemical bonds linking the fibres together in a way not known. It is assumed that the strength is derived from those bonds (relatively few) together with the physical forces acting between the fibres. The gel will tend to have a characteristic strength, but the strength of the structure as a whole should depend upon the amount of the gel in the space available to it.

The Volume of Gel.

$$\text{The gel: space ratio is } X_A = \frac{\text{volume of gel}}{\text{space}} = \frac{2.06 \, c v_c \alpha}{c v_c + w_0}$$

where

c is the weight of cement in grammes,

v_c is the specific volume of cement in cubic centimetres per gramme (0.319).

α is the fraction hydrated,

w_0 is the original volume of water, and

$$X_A \text{ is } \frac{0.647\alpha}{0.319\alpha + \frac{w_0}{c}}$$

The volume of gel produced per unit volume of cement consumed in making it is 2.06; in other words, if 1 cc. absolute volume of Portland cement is hydrated there will be produced 2.06 cc. of gel plus the non-gel constituents; 2.06 times the weight of the cement times the specific volume will give the actual amount of

gel produced if it is known how much of the cement has hydrated; α is the coefficient of hydration—that is the fraction of the cement that is hydrated and that is producing the same material all the time. The space available is the volume of the water-filled space there originally plus the space vacated due to the reaction of the cement. It is seen that for a particular cement the specific volume of which is 0.319 the gel:space ratio is a function of the degree of hydration and the water-cement ratio.

Fig. 7 shows how strength conforms to this relationship. For each of three different mixtures there are six different ages from seven days to two years. It is not necessary to distinguish between mixture or age if the gel:space ratio is known. The strength is proportional to the cube of the gel:space ratio; a cubical function is what might be surmised due to filling the space in this way. The

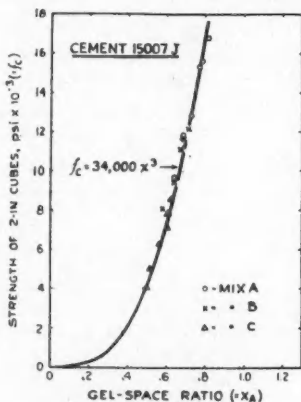


Fig. 7.

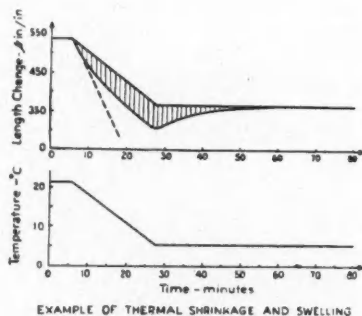


Fig. 8.

factor of 34,000 might be considered as a measure of the intrinsic strength of the gel itself, because that is what it would be when the gel:space ratio is unity. The strength of an actual paste is not that of the gel only with water-filled space, for it may also contain air-filled spaces. Another definition is needed. There are other voids that represent incomplete consolidation of the original paste; or, in the case of concrete, the air entrapped in the mixture.

The effect of air is similar in magnitude to the effect of water. An increase in the amount of air has an effect similar to an increase in the porosity of the paste, equal increases having nearly equal effects.

Hygrothermal Effects.

Apart from the shrinking and swelling that take place when concrete gains or loses water, there is a hygrothermal volume change that is actually a shrinking and swelling but does not involve gain or loss of water. This is related to the fact that the gel water has a different entropy from the capillary water, and, if there is an existing equilibrium between the water in the gel pores and those in the

capillary pores at a given temperature, a change in temperature will disturb that equilibrium and will require a transfer of water to or from the gel.

$dF = (\bar{S}_g - \bar{S}_c) dT$; dF = free-energy potential produced by change dT ;

\bar{S} = ntropy; g and c = gel water and capillary water.

If the temperature change after equilibrium has been reached, there must be a transfer of water from gel pores to capillary pores, or vice versa, to produce a new equilibrium. The lower curve in Fig. 8 gives temperature records against time for a particular experiment. The upper diagram shows the length of a specimen immersed in water also plotted against time, and shows the simultaneous corresponding changes. As the temperature was lowered the specimen shrank along the lower full line, and when cooling was stopped and the temperature kept constant it swelled back to the level corresponding to the normal thermal coefficient. The upper full line is what the locus would have been had no transfer of water from capillary to gel taken place. It is a direct demonstration of what could be deduced from these thermodynamic relationships. Fig. 9 is another example. Starting from A, the length of a specimen cooled at about 1 deg. per minute followed the locus B instead of the dotted line. At C cooling was stopped; if the

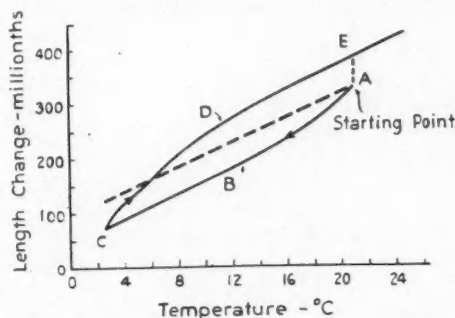


Fig. 9.

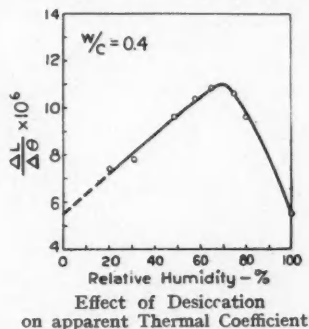


Fig. 10.

temperature had been maintained the curve would have moved up to the dotted line, but if the temperature were raised the specimen would swell and follow the locus D. The consequence from the practical point of view is that the concrete does not, as is usually assumed, have a constant thermal coefficient. This is particularly prominent if the material does not have access to water outside its own boundaries, and particularly if it is not saturated.

The true thermal coefficient does not vary, although it apparently varies. Hygrothermal volume change is a maximum when the humidity in the paste is about 70 per cent. of saturation and is nil in a dry specimen. It is transient in an immersed specimen: it appears and disappears, the water from outside enters and cancels it. When there is no water outside and the humidity is 70 per cent. there is the maximum effect. In Fig. 10 the change in length per unit length per degree is plotted against saturation on a humidity basis, and at about 70 per cent. there is about double the apparent thermal coefficient for the saturated and the

dry condition; actually, much larger effects than this have been observed. Fig. 11 shows the same effect in two concretes, but the effect is reduced by the restraining effects of the aggregates. In the upper part is a line for paste steam-cured at high pressure—a way of eliminating the colloidal characteristics of the paste and changing it to a non-colloidal material; it is seen that there is no such effect.

Permeability of Hardened Cement Paste.

Permeability depends on the fact that the gel itself is permeable and that the capillaries are permeable—and the permeability is a function of the relative proportions of the two. Fig. 12 shows the capillary porosity in relation to permeability, and it is seen that for different cements and different ages this relationship is maintained very well. The change in permeability with the time is enormous, as is shown in Table II. Fresh paste has a permeability of 1.15×10^{-9} . After twenty-four days of curing the coefficient of permeability of this paste, which had an

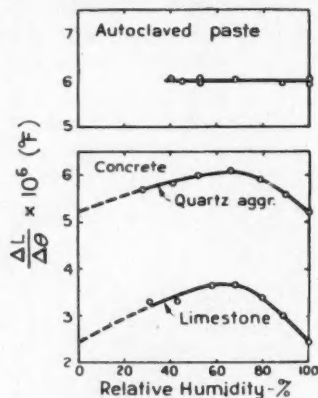


Fig. 11.

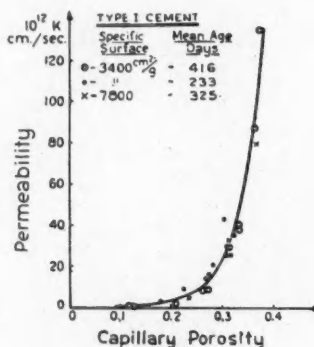
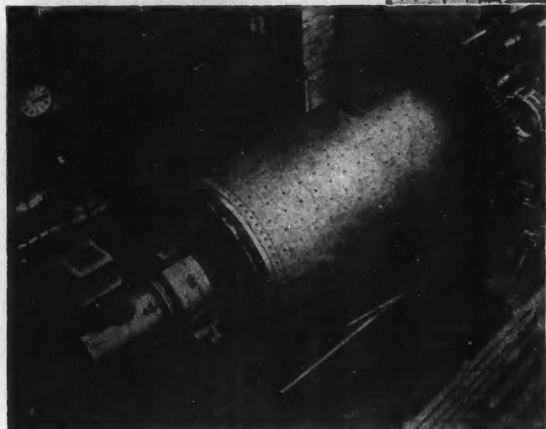
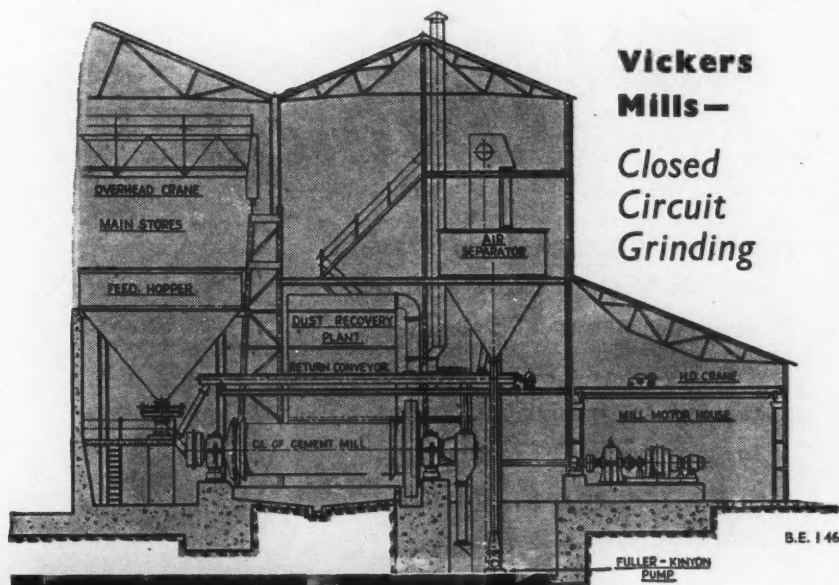


Fig. 12.

original water-cement ratio of 0.645, is reduced to 4.6×10^{-11} . The porosity, which is the total space occupied by evaporable water, begins at 67 per cent. of the volume of the fresh paste and drops to 48 per cent. This is a case of very low permeability and very high porosity. If the permeability is compared with that of rock free from visible flaws, Table III shows that coefficients of permeability vary from 3.45×10^{-13} to 2.18×10^{-9} . The water-cement ratios of mature cement pastes that will have the same permeabilities as these rocks are also given. But these rocks will have porosities of 1 to 2 per cent. or less, while the cement pastes have porosities from 2 per cent. to 50 per cent. This combination of high porosity and low permeability is the most fundamental reason for the use of entrained air in concrete.

Referring to Fig. 5, imagine water freezing in the capillary cavities (C), that all the other pores are full of water, and that the boundaries represent the outside of the sample. If a cavity is full of water and the water freezes, the increase in



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TABLE II. CHANGE OF PERMEABILITY AND POROSITY WITH AGE.
Type I cement. Specific surface 1800 Wagner. Water-cement ratio 0.645.

Age in days	Porosity (per cent.)	Coefficient of permeability $\times 10^{12}$ (cm. per second)
Fresh paste	67	1,150,000,000
1.. .. .	63*	36,300,000*
2.. .. .	60*	2,050,000*
3.. .. .	57*	191,000*
4.. .. .	55*	23,000
5.. .. .	53	5,900
7.. .. .	52	1,380
12.. .. .	51	195
24.. .. .	48	46

*Interpolated.

TABLE III. PERMEABILITY OF ROCKS AND MATURE CEMENT PASTE.

	Permeability of rock (K cm. per second)	Water-cement ratio for same K
Dense trap	3.45×10^{-13}	0.38
Quartz diorite	1.15×10^{-12}	0.42
Marble.. .. .	3.34×10^{-12}	0.48
Marble.. .. .	8.05×10^{-11}	0.66
Granite	7.48×10^{-10}	0.70
Sandstone	1.72×10^{-9}	0.71
Granite	2.18×10^{-9}	0.71

volume results in a dilation of the cavity equal to 9 per cent. of its volume, or the forcing to the boundaries of excess water—one or the other, or some of both. It is therefore a problem of hydraulics. The pressure that will be developed as the ice forms is obviously a function of the distance to the boundary, the permeability of the intervening material, and the rate at which the ice forms. It is known that cement paste in the water-soaked condition will develop pressure. Another mechanism causes it to be damaged when frozen if the layer of paste is more than three or four thousandths of an inch thick, but this creates such pressure that it causes the paste to dilate, although such dilation can be prevented by entrained air. In the case of water-soaked mature paste entrained air divides it into layers so thin that when the water freezes in the saturated paste the excess produced by freezing can escape without producing excessive pressure. It is not a matter of space: all concretes contain more than enough space to accommodate the excess water; 0.5 per cent. of air space in concrete is enough to accommodate the increase in the volume of water produced by freezing. It is a matter of friction, that is the resistance to the displacement of the water to the spaces. It is necessary to include 3 per cent. to 5 per cent. or more air to protect the paste by providing a sufficient number of bubbles to divide the paste into very thin layers and thereby keep the pressures below the damaging intensity.

In the case of cement paste mixed in a vacuum and containing no entrapped air, as it came below freezing point there was a large dilation (1600 millionths of

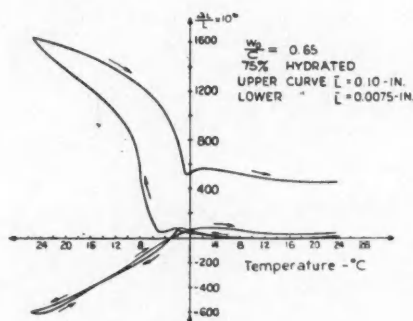


Fig. 13.

an inch) causing a high stress; it collapsed when it thawed but left a residual dilation due to structural damage produced by freezing. This is what occurs in concrete. If the quantity of air is increased 2 per cent. to 16 per cent. there is no dilation at all; this is normal behaviour for concrete that is immune to frost action. It should be remembered that it is not the percentage of air but the number of bubbles per unit volume that controls dilation. In Fig. 13 is contrasted the behaviour of paste that is free from air and paste that has enough air to protect it; the effect is to produce shrinkage if the paste is so protected that it is not damaged by freezing.

All the properties of concrete are influenced and to some degree explained by the structural features reviewed. The distribution of water between gel and capillary pores is a function of temperature. It is also a function of pressure, and the distribution of water between one part of a concrete member and another is a function of pressure or stress in the member. Water might be expected to be continually moving in concrete because the gels respond to changes in humidity, pressure, temperature, and stress. So long as these variable ambient conditions are present, some parts of the structure are almost continually in a state of flux and, especially while they are in a state of flux, a superimposed stress will cause movement—and that is one aspect of the “creep” of concrete—movement of water from one part to another produces shrinkage where it leaves and swelling where it goes. For example, a beam subjected to a constant load appears to yield slowly under stress; of course it does, but part of it is simply a shrinking and swelling effect internally, not necessarily due to loss of water to the outside. In many problems related to concrete an explanation seems to arise from this concept of the colloidal structure. The work is not complete, but the foregoing is based on a large amount of study and carefully collected data. It is thought that the structure of cement gel is colloidal, and that its colloidal nature is responsible for its behaviour.



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Cement Industry in Central America.

ECUADOR.—It is understood that the only factory now making cement in Ecuador is that of Fabrica de Cemento Nacional Rocafuerte at Guayaquil. A new factory is in course of construction in the province of Chimborazo, and it is proposed to construct another at Guapan in the province of Canar. On the assumption that the Rocafuerte factory will double production within the next year, that the Chimborazo works will be producing by mid 1956, and that the factory at Guapan will come into existence, it is considered that Ecuadorean requirements for the next ten years should be met. It is understood that capital for the Guapan plant has not yet been provided.

PERU.—At present there are only two companies producing cement, namely Cia. Peruana de Cemento Portland, whose plant some 45 kilometres south of Lima has a capacity of 1,350 tons daily, and Cia. de Cemento Chilca, S.A., whose factory, 80 km. south of Lima, started manufacture in February, 1955, with an initial capacity of 250 tons per day, and is stated to have sufficient raw material for a daily capacity of 2,000 tons.

Cia. de Cemento de Chiclayo, S.A., which is owned by the Cia. Peruana de Cemento Portland, is to start production with a capacity of 130 tons a day, at the beginning of 1956; the works is about 750 km. north of Lima. Another company, Cia. de Cemento Portland del Peru, S.A., has a works under construction at Pacasmayo, 660 km. north of Lima, which should commence production in about two years' time at the rate of 340 tons a day; this company recently obtained a loan from the International Bank for Reconstruction and Development. Projects for the establishment of cement factories in Sicuani (near Cuzco), with an initial capacity of 250 tons daily, and at Juliaca (Southern Peru), of which no details are yet available, are being considered. The present Government is sympathetic towards projects for increasing the industrialisation of the country.

BOLIVIA.—The only cement factory in production in Bolivia is at Viacha, near La Paz, of which the output was originally 3,300 tons per month but is now less. According to the Bolivian authorities, this plant is antiquated and there is a risk that its failure would leave the country without any supply of cement. Another factory is under construction at Sucre and it is estimated that it will be complete in 1956. The Bolivian Development Corporation is negotiating with a French firm that is interested in establishing a factory in Cochabamba. It is understood that the Directorate of Industry of the Ministry of National Economy is anxious to encourage the development of the cement industry.

COLOMBIA.—It is thought that, apart from high tariffs, special incentives by the Government for the encouragement of the cement industry in Colombia are remote, but local governments offer tax concessions in the hope of attracting the establishment of industries in their areas. The existing cement works in Colombia are unable to supply the demand.

Brazilian Specification for Portland Cement.

The Brazilian Government announces that in future all Portland cement imported into that country must comply with a specification prepared by the Government in collaboration with the National Institute of Technology of Rio de Janeiro and the Institute of Technological Research of Sao Paulo. The principal clauses of the specification are as follows.

Loss on ignition, maximum 4 per cent. (tolerance 0.3 per cent.).

Insoluble residue, maximum 0.85 per cent. (tolerance 0.15 per cent.).

Sulphuric anhydride, maximum 2.5 per cent. (tolerance 0.15 per cent.).

Magnesium oxide (MgO), maximum 6 per cent. (tolerance 0.4 per cent.).

Residue on sieve with meshes of 0.075 mm., maximum 15 per cent. by weight.

Initial set, not less than one hour after the addition of water.

Expansion not to exceed 10 mm.

Compressive strength of 1:3 mortar, not less than 80 kg. per square centimetre (1,140 lb. per square inch) at three days, 150 kg. per square centimetre (2,140 lb. per square inch) at seven days, and 250 kg. per square centimetre (3,550 lb. per square inch) at 28 days.

Cement Production in Mexico.

Cement production in Mexico is reported to have been 1,765,000 tons in the year 1954. This compares with 808,000 tons in 1945 and 1,672,000 tons in 1953.

Cement Production in the Philippines.

Cement production in the Philippines for the year ended June 30, 1955, was 345,000 tons worth about £4,940,000.

New Cement Works in Honduras.

The Honduran Government and National Development Bank have studied the idea of erecting a cement works. It is expected that a company will shortly be formed to carry out the work.

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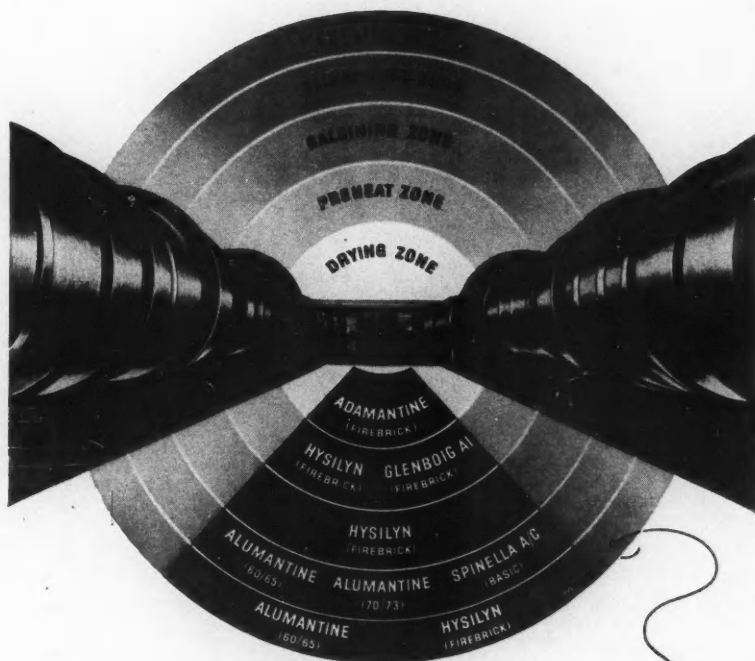
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